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ARTIFICIAL MARSHES FOR WASTEWATER TREATMENT

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ABSTRACT

A promising natural means of wastewater treatment has been developed by NASA at the National Space Technology Laboratories (NSTL) in South Mississippi during the past 15 years. This biotechnology involves the use of marsh plants, microorganisms and high surface area support media such as rocks. The symbiotic relationship that exists between microorganisms and plant roots can result in synergistic action toward degradation and removal of biochemical oxygen demanding (BOD) substances from domestic sewage and toxic chemicals from industrial wastewaters.

When plants such as reed (Phragmites communis), cattail (Typha spp.), canna lily (Canna flaccida), arrowhead (Sagitaria latifolia), arrow-arum (Peltandra virginica), pickerelweed (Pontederia cordata) and green taro (Colocasia esculenta) are planted in rock filters, artificial marshes are produced which are highly biologically active. These filters can reduce BOD_5 levels in septic tank and oxidation lagoon effluents from 110-50 mg L^{-1} to 10-2 mg L^{-1} in 12 to 24 h. These marsh filters can also reduce toxic organic chemicals such as benzene from 9 mg L^{-1} to 0.05 mg L^{-1} in 24 h in addition to removing toxic heavy metals and radioactive elements from contaminated waters.

Keywords: Aquatic plants, sewage effluent, industrial effluents, artificial wetland, gravel bed system.

INTRODUCTION

The treatment of domestic sewage and removal of hazardous chemicals from contaminated water is a problem confronting communities and cities throughout the United States and other countries. Wastewater treatment is an integral part of the water crisis that is emerging throughout the world. Even areas of the U.S. and other parts of the world with a plentiful supply of water are facing problems because the water is becoming contaminated with sewage and/or hazardous chemicals. Therefore, one of the

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most urgent environmental needs in the world today is a simple, low cost means of wastewater treatment and water reuse. A promising means of utilizing vascular aquatic plants for wastewater treatment has been investigated by NASA and other scientists during the past 15 years (Bastian and Benforado, 1983).

Much success has been achieved in utilizing higher plants and microorganisms in developing low cost wastewater treatment and recycling processes. The use of artificial marshes for treating both domestic and industrial wastewater is discussed in this report.

DOMESTIC SEWAGE TREATMENT

The first phase of research conducted by NASA in wastewater treatment utilizing aquatic plants was begun at NSTL in 1971, and involved the use of water hyacinth (Eichhornia crassipes) and duckweed (Lemna, Spirodela, and Wolffia sp.) floating aquatic plants (Wolverton and McDonald, 1976a,b; 1977a,b; 1978a,b; 1979a,b,c,; 1980; 1981a,b; Wolverton and McKnown, 1976; Wolverton et al., 1976). These plants were used to upgrade sewage lagoons at NSTL in 1975. By using water hyacinths and duckweed in lieu of conventional activated sludge processes, NASA has realized cost savings at NSTL of several million dollars over the past 11 years of operation.

Although the water hyacinth/duckweed combination has been effective for treating wastewater for the past 11 years at NSTL, severe hyacinth kill-back during several cold winters has occurred. Water hyacinth was completely eliminated from one small marsh system and was replaced with water pennywort (Hydrocotyle umbellata), a more cold-tolerant plant. For the past six years the pennywort/duckweed system has worked very effectively without any plant harvesting. Other researchers have also demonstrated the value of these and other aquatic plants in treating wastewater (Culley and Epps, 1973; Dinges, 1982; Reddy, 1983; Reddy and DeBusk, 1984, 1985a,b; Reddy et al., 1983).

In an effort to increase the geographical range and effectiveness of floating aquatic plant systems, an advanced hybrid system was developed which combined emersed, cold-tolerant and salt-tolerant plants with microbial filter technology. The first hybrid system consisted of an anaerobic sludge collecting and digesting chamber followed by an up-flow rock filter in which reed (Phragmites communis) or rush (Juncus effusus) was grown (Wolverton, 1982; Wolverton et al., 1983).

The hybrid system has changed over the past several years by adding aerobic and facultative lagoons to collect and digest sludge. The reeds and rushes have also been replaced in most cases by more aesthetically desirable plants such as the canna lily, arrowhead, arrow-arum, elephant ears, pickerelweed and water iris which performed equally well (Table 1). The canna lily,

TABLE 1. Artificial marsh filters for removing BOD_5 from domestic sewage.†

Marsh plants	Concentration before and after exposure to marsh filter	
	Initial	After 24 h
	------------mg L^{-1}------------	
Reed	306.0‡	36.0
(Phragmites communis)	71.7	2.8
Cattail	80.1	8.3
(Typha latifolia)		
Arrowhead	75.0‡	5.0
(Sagittaria latifolia)		
Arrow Arum	53.0	2.0
(Peltandra virginica)		
Canna Lily	116.0‡	12.0
(Canna flaccida)	64.0	3.0

†Three (3) or more different replicates were performed.
‡Two initial ranges.

arrowhead, pickerelweed and water iris also produce beautiful yellow, red, orange, white and blue flowers.

Although microbial rock filters have been used to treat sewage for over 90 years and the ability of aquatic plants to enhance sewage treatment in natural marshes has been recognized for many years, only recently have the two processes been combined. The combination and optimization of microbial filters and higher plants into an artificial marsh has produced one of the most promising wastewater treatment technologies since development of the trickling filter process in 1893.

Although this technology is relatively simple, it is very important that sound engineering practices be used in the design of these filters. It is also important that filter depth be considered, especially in the last section of the filter, to assure that aerobic conditions are achieved before discharge. A dissolved O_2 level of 1.5 mg L^{-1} or more is required to achieve low BOD_5 effluent levels (<10 mg L^{-1}).

Since the application of the microbial-plant filter is new and only a limited number of small systems have been in operation over the past several years, engineering design data is still being generated. Several small systems, 0.74-3.78 m^3 d^{-1}, have been in operation in Mississippi for several years (Wolverton et al., 1984). There have been seven microbial-plant filter systems ranging in size from 7.6 to 1325 m^3 d^{-1} designed for use in Louisiana in the past year. Several of these systems are now under construction and scheduled to be operational by late 1986. These filters were designed to treat wastewater discharged from septic tanks (Figures 1 and 2) and sewage lagoons (Figure 3).

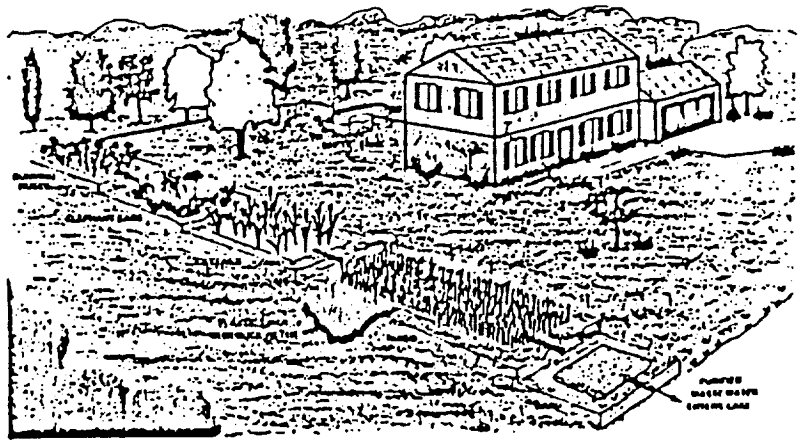

FIGURE 1. Single home wastewater treatment system using plants.

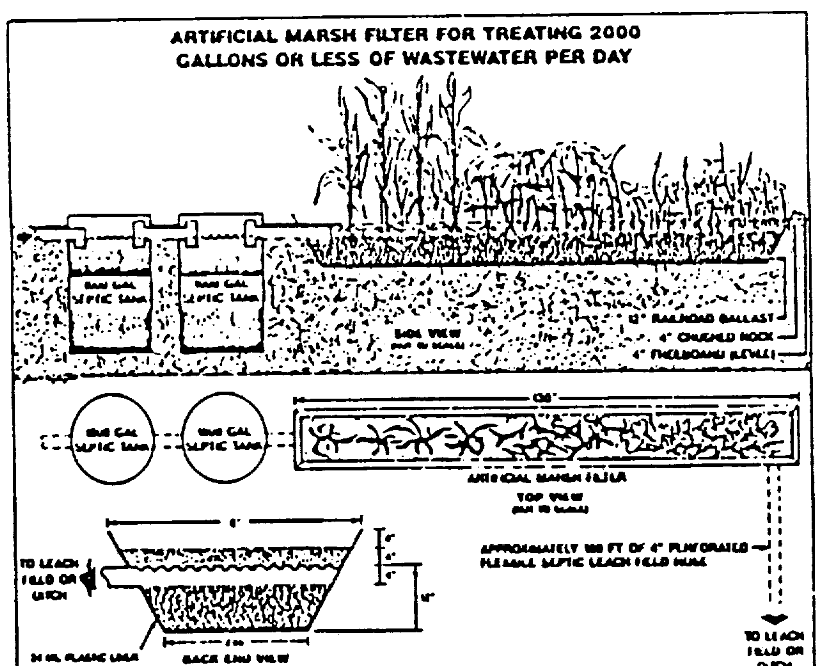

FIGURE 2. Artificial marsh filter for treating 7.57 $m^3\ d^{-1}$ or less of wastewater.

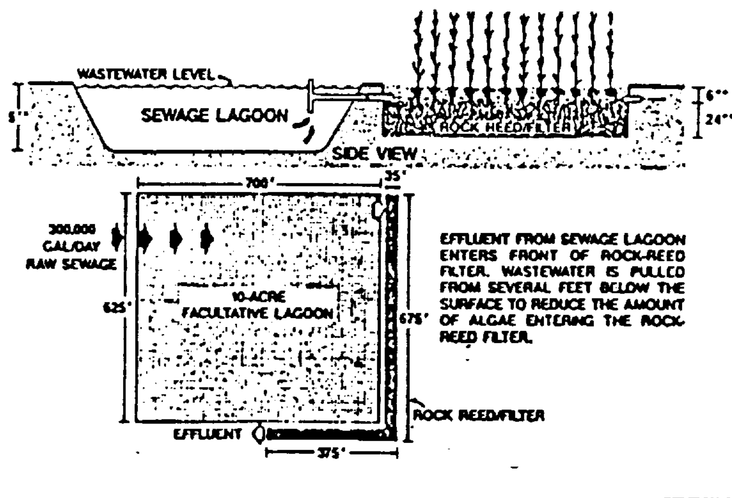

FIGURE 3. The use of artificial marshes (rock-reed filters) to upgrade sewage lagoons to meet advanced wastewater treatment standards.

Marsh filters are also capable of treating wastewater discharged from any system provided sludge is removed to prevent filter clogging. Marsh filters can be designed to achieve various levels of BOD_5 and TSS removal, ranging from secondary levels of 30 mg L^{-1} to tertiary levels of 5 mg L^{-1} or less.

INDUSTRIAL WASTEWATER TREATMENT

The ability of microorganisms to degrade organic chemicals is well documented (Bouwer and McCarty, 1981,1983a,b; Bouwer et al., 1981; Eaton and Ribbons, 1982; Gibson, 1977,1980; Haber et al., 1983; Kellogg et al., 1981; Keyser et al., 1976; Kilbane et al., 1982; Klecka and Maier, 1985; Rittman and McCarty, 1980; Tabak et al., 1981; Wilson and Wilson, 1985; Wolverton and McDonald, 1977, 1981,1986; Wolverton et al., 1981,1984; McDonald, 1981) (Tables 2 and 3). Microorganisms can adapt to utilizing carbon sources from various organic chemical structures. This adaptation occurs through recruiting various genes from existing plasmids to make new plasmids. The new plasmids then code for enzymes necessary to convert the C sources into compounds useful for energy and cell mass synthesis (Kellogg et al., 1981).

Biological processing techniques have been developed which enable adapted microorganisms to be retained in the biological treatment unit or filter for periods much greater than the hydraulic retention time. Mean cell residence times of approximately 100 d can be achieved with short hydraulic retention

TABLE 2. Artificial marsh filters containing reed (Phragmites communis) for removing toxic organics from domestic sewage and tap water.†

Organic	Solution	Concentration Before and After Exposure to Marsh Filter: Initial	Final: 3 h	Final: 6 h	Final: 24 h
	mg L^{-1}				
Benzene	Tap water	9.33	0.95	0.39	0.05
Benzene	Domestic sewage	9.59	0.85	0.60	0.23
Toluene (methyl benzene)	Tap water	6.60	0.78	0.22	0.005
Toluene (methyl benzene)	Domestic sewage	7.13	0.66	0.49	0.12
p-Xylene (p-dimethyl-benzene)	Tap water	4.07	0.65	0.43	0.14
p-Xylene (p-dimethyl-benzene)	Domestic sewage	4.34	0.69	0.65	0.35

†An average of 12 replicates were performed with each solution.

TABLE 3. Artificial marsh filter containing reed (Phragmites communis) for removing chlorinated hydrocarbons from contaminated river water.†

Organics	Concentration Before and After Exposure to Marsh Filter: Initial	4 h	24 h
	μg L^{-1}		
Chloroform	837.7	387.5	263.2
Tetrachloroethylene	457.3	161.7	112.4

†Forty-eight (48) replicates were performed.

times. This characteristic of the microbial filter process makes it very appealing for treating domestic sewage and industrial chemical wastewater.

The efficiency and versatility of the microbial filter process has undergone significant improvement recently with the addition of vascular aquatic plants to the system (Wolverton and McDonald, 1981,1986; Wolverton et al., 1984). The ability of plant roots to absorb, translocate and metabolize organic chemicals was recognized in the early 1930's. This phenomenon made possible the development of systemic pesticides and opened up a new industry. A highly biologically active artificial marsh filter can be developed by the use of plant roots and rocks. Nutrient-enriched waters such as domestic sewage should be used to condition the artificial marsh filter before adding wastewater containing organic chemicals. Once the microorganisms are established on and around the plant roots, they form a symbiotic relationship with the plants which results in synergistic actions toward degradation and removal of organic chemicals from the wastewaters exposed to this filter. These reactions are very complex and are not fully understood.

During microbial degradation of the organics, certain fragments (metabolites) are produced which the plants absorb and utilize along with minerals as a food source. The microorganisms also utilize certain metabolites produced by plant roots as a food source. By each removing the others waste products, this allows a reaction to be sustained in favor of rapid removal of organics from the wastewater stream. The plants also add to the microbial filter the capability of removing toxic heavy metals and radioactive elements from the wastewater stream flowing through the artificial marsh (Wolverton et al., 1976; Wolverton and McDonald, 1977; McDonald, 1981). The plants remove the soluble metals and radioactive elements from the wastewater by absorption and concentration.

PLANT MANAGEMENT REQUIREMENTS

When plants are used to concentrate non-biodegradable substances and remove them from wastewater, a plant harvesting and storage process must be developed. One scheme that has been in use for over 10 years at NSTL is the use of a clay-lined pit. The harvested plants containing heavy metals such as silver are stored in the clay-lined pit which has an overflow outlet back into the front end of the marsh filter. Most aquatic plants are over 90% water, therefore, their volume is reduced to 5-10% of the original volume after decomposition.

There are several options available for managing plants grown in wastewater containing domestic sewage and/or industrial wastewater that contains biodegradable organics and non-toxic elements. The simplest method involves no harvesting as occurs in natural marshes. Another possible option is the controlled burning of dead plant material during late winter or early spring before the appearance of new plant shoots. The use of animals such as goats for controlled grazing of the marsh plants is an interesting alternative to burning or mechanical harvesting (Figure 4). This method can only be used after assurance that the plants are free of toxic chemicals.

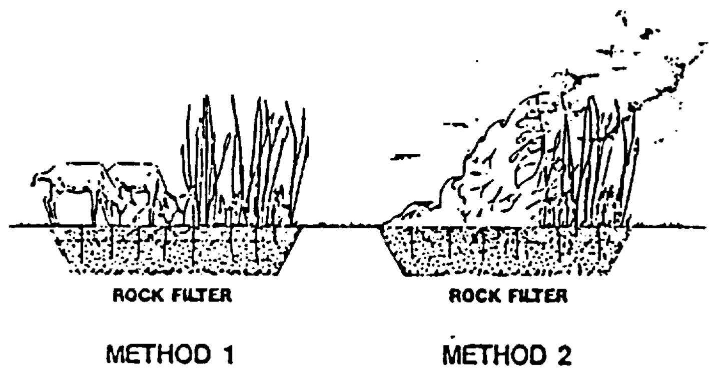

FIGURE 4. Marsh plant harvesting methods.

ADVANTAGES AND DISADVANTAGES OF USING ARTIFICIAL MARSHES FOR WASTEWATER TREATMENT

The artificial marsh concept for treating and recycling wastewater is, in most cases, a viable alternative to conventional mechanical treatment systems.

Advantages of the artificial marsh treatment process over mechanical systems are: 1) less costly to install in most locations; 2) lower operational and maintenance costs; 3) non-technical personnel can operate and maintain; 4) more flexibility and less susceptibility to shockloading; 5) less energy required to operate, and 6) greater reliability. The major disadvantage of the artificial marsh process is the increased land area required.

DISCUSSION AND RECOMMENDATION

Artificial marshes can be designed and constructed in several different configurations. The most effective marshes for treating domestic and industrial wastewaters include rock filters. Each filter should be designed in accordance with the receiving wastewater stream. Large rocks should be used in the front portion of marsh filters receiving algal laden discharge water from sewage lagoons during the summer months to minimize filter clogging. An area of 1.6-2.0 ha of marsh filter is required to treat 3,800 m^3 of sewage lagoon effluent per day. Marshes installed in colder climates will require a longer retention time in the filter, different types of plants, and increased land area. Different types of wastewater may also require different retention times and different types of marsh plants.

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